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Patents ADP number *(if you know it)*	8699597001	
If the applicant is a corporate body, give the country/state of its incorporation	UNITED KINGDOM	
4. Title of the invention	A BOUYANCY CONTROL SYSTEM	
5. Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	ABLETT & STEBBING CAPARO HOUSE 101-103 BAKER STREET LONDON W1U 6FQ	
Patents ADP number *(if you know it)*	00006551001	

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Date

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A BUOYANCY CONTROL SYSTEM

The present invention relates to a buoyancy control system, in particular a buoyancy control system for controlling the buoyancy of an underwater submersible.

Unmanned submersibles are used for studying the undersea environment. There are two principal types of such submersibles, remotely operated vehicles (ROVs), and autonomous underwater vehicles (AUVs).

ROVs are free swimming vehicles tethered to a ship via an umbilical cable link which supplies electrical power and/or telemetry to the ROV. ROVs are effectively used, for example, in the oil industry for sub-sea surveys and operations; however, since they require the constant presence of a surface vessel and crew, ROV running costs are high.

Due to the high running costs of ROVs, they are increasingly being replaced with AUVs. One such type of AUV is a so-called "drifter", i.e. an AUV which uses buoyancy control to hold position within the water at predetermined depths to collect data. Having collected data, the drifter rises to the surface to transmit the data to a home station, and then resubmerges to record further data, for example at a different site. Another type of AUV is a so-called "lander", which lands on the seabed to collect data, and then rises to the surface to transmit the data to a home station. Other types of AUV are also known, for example powered unmanned submarine-type vessels.

However, a problem with existing AUVs is that of "trim", i.e. buoyancy in water. Existing AUVs are designed to float with

typically only a few kg (for example, 2 or 3 kg) of positive buoyancy, which reduces manoeuvrability forces, resulting in a longer mission time. In addition, whenever an instrument is either attached to or removed from the AUV, it must be manually re-trimmed, which consumes valuable ship time. Furthermore, if the AUV is required to drop off or pick up an object during the mission then buoyancy is affected, which can result in either a rapid rise to the surface or, worse, drop to the seabed. Indeed, AUV buoyancy may be affected by mere changes in seawater density, to the extent that the AUV may not be able to surface, and thus be recovered.

In addition, a particular problem with AUV landers is the impact of the lander on the seabed. This impact can disturb the environment the lander is intended to record, which thus affords false readings. For example, the bow wave in front of a sinking lander can disperse superficial sediment on the surface of the seabed, which the lander may be intended to study, and the noise of the lander impact on the seabed may influence the behaviour of animals intended to be studied.

A further problem with unmanned (and indeed manned) submersibles is that of buoyancy control at depth (for example, 3000m or greater), due to the pressure of seawater at such depths. There are two main types of known buoyancy control system.

The first type of buoyancy control system uses compressed air, which is conventionally used for buoyancy control on manned submarines. In these systems, buoyancy is decreased by filling ballast tanks with water, and buoyancy is increased by forcing the water from the tanks using compressed air. The disadvantages of compressed air systems are firstly that they

require large amounts of power (hence their use on large, high-power manned submarines), and secondly that they are only operable to depths of hundreds of metres. The use of compressed air at greater depths becomes inefficient and dangerous, due to the very high air pressures required.

The second type of buoyancy control system uses a closed loop oil pumping system. In these systems, oil is pumped to and from a flexible bag, to thereby increase and decrease the volume of the bag, and accordingly the buoyancy of the submersible. The advantages of oil pumping systems are that they require relatively little power, and hence can be used on smaller submersibles, and can operate at much greater depths than compressed air systems, for example 3000m or greater. However, the buoyancy change afforded by oil pumping systems is relatively small, for example less than 1kg.

The present invention seeks to provide a buoyancy control system which can overcome the problems described above.

According to the present invention there is provided a buoyancy control system for controlling the buoyancy of an underwater submersible, which system comprises a reservoir for containing seawater, an inlet for the ingress of seawater into the reservoir, an outlet for the egress of seawater from the reservoir, and a hydraulic system for pumping seawater from the reservoir through the outlet, the hydraulic system comprising a hydraulic pump and a pressure multiplier, the hydraulic pump for applying pressure to the pressure multiplier, and the pressure multiplier for increasing the pressure applied thereto by the hydraulic pump, and for applying the increased pressure to seawater from the reservoir to thereby pump the seawater through the outlet.

The present invention can thus provide a buoyancy control system which is low-power, for example 150W, operating from one or more 12 volt car batteries (for example, two 12V batteries, i.e. a 24V battery source) or from an external power source through an umbilical. The system can operate at depth, for example 3000m or greater, and can afford a higher buoyancy change than existing closed loop systems, for example, for practical use, up to 35kg buoyancy change. However, the system can also provide a high level of buoyancy control, or "trim", for example less than 100g, preferably as low as 50g. The low-power requirement of the system of the present invention allows the system to be relatively lightweight and compact, which in turn allows it to be used as a "bolt-on" to existing underwater submersibles. When battery powered, the system of the present invention preferably uses sufficiently low power to enable three complete buoyancy cycles to be completed, at full depth (for example, 3000m or greater).

The system of the present invention comprises a reservoir for containing seawater. Suitable reservoirs are commercially available and known to those skilled in the art. For example, a suitable reservoir comprises a glass, steel or titanium sphere, which has sufficient strength under pressure, according to the depths at which the system is to operate, for example 3000m or greater for preferred embodiments of the present invention. The reservoir should have a capacity large enough to provide the required buoyancy change, preferably 25kg or greater, for example up to 35kg.

The system of the present invention also comprises an inlet for the ingress of seawater into the reservoir. The inlet conveniently comprises a valve, having a suitable pressure

rating for the depths at which the system is to operate. For example, for some preferred embodiments of the present invention the inlet valve has a pressure rating of $3x10^7$Pa (300 bar). The inlet valve is preferably controlled, i.e. opened and closed, by an electronic control system.

The system of the present invention further comprises a hydraulic system for pumping seawater from the reservoir through the outlet, the hydraulic system comprising a hydraulic pump and a pressure multiplier, the hydraulic pump for applying pressure to the pressure multiplier, and the pressure multiplier for increasing the pressure applied thereto by the hydraulic pump, and for applying the increased pressure to seawater from the reservoir to thereby pump the seawater through the outlet.

The hydraulic pump is preferably low power, for example having a 12 or 24 volt, 150 watt rating. Such pumps are relatively lightweight and compact, and preferred hydraulic pumps for use in the present invention can operate from one or more commercially available car batteries, or from an external power source via an umbilical.

The pressure multiplier of the hydraulic system is used to increase the pressure applied thereto by the hydraulic pump, and apply the increased pressure to seawater from the reservoir to thereby pump the seawater through the outlet. The pressure multiplier preferably comprises input and output surfaces in pressure transmitting relation, the output surface having a surface area less than the surface area of the input surface. The pressure increase generated by the pressure multiplier is determined by the ratio of surface areas of the input and output surfaces. The input surface may conveniently

comprise a plate, and the output surface may conveniently comprise a plunger or piston. In this way, a relatively low pressure applied to the input surface by the hydraulic pump can be transmitted as a relatively high pressure to seawater from the reservoir, to thereby expel the seawater through the outlet.

The system of the present invention preferably comprises an exit chamber into which seawater can enter from the reservoir, and from which the seawater is expelled through the outlet by the hydraulic system. The system preferably further comprises a non-return valve or valves associated with the chamber, for preventing seawater from reentering the reservoir. In these preferred embodiments of the buoyancy system, the pressure multiplier is preferably a reciprocating pressure multiplier, in that it can reciprocate between a first position in which seawater can enter the exit chamber from the reservoir, and a second position in which the seawater in the exit chamber has been expelled from the exit chamber.

In preferred embodiments of the present invention, seawater can be pumped from the reservoir as follows. At the start of each cycle, seawater is allowed to enter the exit chamber from the reservoir. A non-return valve or valves associated with the chamber ensures that the seawater in the chamber does not reenter the reservoir. When the chamber has filled with seawater, the hydraulic pump applies hydraulic pressure to the input surface of the pressure multiplier, through a suitable hydraulic fluid (for example, oil), which increases the applied pressure, and transmits the same to the seawater in the chamber via the output surface, thereby expelling the seawater in the chamber through the outlet. When the seawater in the chamber has been expelled, the cycle is repeated. In

preferred embodiments, the reservoir can be emptied in less than 2 hours.

The hydraulic system of the present invention preferably further comprises one or more position detectors, for example a proximity detector or switch, for detecting the position of the pressure multiplier. When the position detector detects that the pressure multiplier is in a position at the end of the cycle described above, i.e. in the preferred embodiments described above, when the seawater has been expelled from the exit chamber and the reciprocating pressure multiplier is in the second position, the electronic control system can cause the pressure multiplier to return to its original position, i.e. the first position in the preferred embodiments described above, to expel more seawater from the reservoir.

The combination of the hydraulic pump and pressure multiplier allows seawater to be pumped from the reservoir at depth, for example at depths of 3000m or greater, whilst requiring low power, and being relatively lightweight and compact.

The system of the present invention preferably further comprises a replacement fluid source for providing fluid to the reservoir to replace seawater expelled therefrom. If seawater expelled from the reservoir is not replaced by a second fluid, then the hydraulic system will be pumping against a vacuum created within the reservoir, which will prevent any further seawater from being expelled. The replacement fluid should have a density less than that of seawater, and accordingly the replacement fluid is preferably a gas, for example air or an inert gas (e.g. nitrogen or argon). The replacement fluid preferably enters the reservoir through a fluid valve, for example a gas spring valve. The

internal pressure of the reservoir may change from, for example, $3x10^7$Pa (300 bar) to 10^5Pa (1 bar) on expelling seawater therefrom.

The buoyancy control system of the present invention preferably further comprises a pressure detector, for detecting the pressure in the reservoir. The pressure detector may comprise, for example, a transducer. The pressure detector helps to prevent excess pressure from building within the reservoir, by providing relevant data to a person or automatic system controlling the buoyancy control system.

As referred to above, the system of the present invention preferably comprises an electronic control system for controlling the system components. Thus, in preferred embodiments of the present invention, an electronic control system controls operation of the inlet and outlet valves, activation of the hydraulic system, for example activation of the hydraulic pump and the position detector, and operation of the replacement fluid source. The electronic control system can thus control the volume of seawater which is contained within the reservoir. The electronic control system may also comprise means for transmitting data concerning the state of operation of the buoyancy control system to a home station.

The buoyancy control system of the present invention can be used for controlling the buoyancy of an underwater submersible, either as an integral part of the submersible, or as a separate "bolt-on" system. In preferred embodiments, the depth of a submersible can be controlled either by pre-programming the electronic control system prior to launch of the submersible, or by the electronic control system responding to depth readings, for example taken by an on-board

depth gauge. The buoyancy system of the present invention can be used with both ROVs and AUVs, but is particularly suited for use with AUVs, due to its relatively light weight and compactness.

According to the present invention there is also provided a hydraulic system for pumping seawater from a submersible reservoir, the hydraulic system comprising a hydraulic pump, and a pressure multiplier, the hydraulic pump for applying pressure to the pressure multiplier, and the pressure multiplier for increasing the pressure applied thereto by the hydraulic pump, and for applying the increased pressure to seawater from the reservoir to thereby pump the seawater from the submersible.

The pressure multiplier preferably comprises input and output surfaces in pressure transmitting relation, the output surface having a surface area less than the surface area of the input surface. The pressure increase generated by the pressure multiplier is determined by the ratio of surface areas of the input and output surfaces. The input surface may conveniently comprise a plate, and the output surface may conveniently comprise a plunger or piston. In this way, a relatively low pressure applied to the input surface by the hydraulic pump can be transmitted as a relatively high pressure to seawater from the reservoir, to thereby expel the seawater from the submersible.

In these preferred embodiments of the hydraulic system, the pressure multiplier is preferably a reciprocating pressure multiplier, in that it can reciprocate between a first position in which, in use, seawater can leave the reservoir to be pumped from the submersible, and a second position in

which the seawater from the reservoir has been pumped from the submersible.

According to the present invention there is further provided a method for pumping seawater from a submersible reservoir, which method comprises applying hydraulic pressure to seawater from the reservoir by a hydraulic system comprising a hydraulic pump, and a pressure multiplier, wherein the hydraulic pump applies pressure to the pressure multiplier, and the pressure multiplier increases the pressure applied thereto by the hydraulic pump, and applies the increased pressure to the seawater to thereby pump the seawater from the submersible.

The method of the present invention is preferably used for controlling the buoyancy of the submersible.

An embodiment of the buoyancy control system and hydraulic system of the present invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 is a schematic of an embodiment of the buoyancy control system of the present invention, and
Figure 2 is a hydraulic circuit diagram of the embodiment represented by the schematic of Figure 1.

Referring to the Figures, an embodiment of a buoyancy control system of the present invention comprises a reservoir 10 for containing seawater. The reservoir 10 may be, for example, a glass, steel or titanium sphere, which has sufficient strength under pressure, according to the depths at which the system is to operate, for example 3000m or greater. The reservoir 10 preferably has a capacity large enough to provide the required

buoyancy change, preferably 25kg or greater, for example up to 35kg.

The system comprises an inlet valve 12 for the ingress of seawater into the reservoir 10, and an outlet valve 14 for the egress of seawater from the reservoir 10. Seawater from the reservoir is pumped from the buoyancy control system by a hydraulic system which comprises a hydraulic pump 16, and a pressure multiplier 18. The pressure multiplier 18 increases the pressure applied thereto by the hydraulic pump, and comprises an input surface, preferably comprising a plate (not separately identified in the Figures) to which pressure is applied by the hydraulic pump, and an output surface, preferably comprising a piston or plunger (not separately identified in the Figures) for applying pressure to seawater from the reservoir 10. The output surface has a surface area less than the surface area of the input surface, the pressure increase generated by the pressure multiplier being determined by the ratio of the surface areas of the output and input surfaces. The hydraulic system is powered by an electric motor 20.

The system preferably further includes an exit chamber (not separately identified in the Figures), into which seawater can enter from the reservoir 10, and from which the seawater is expelled by the hydraulic system. The pressure multiplier 18 is preferably a reciprocating pressure multiplier, in that it can reciprocate between a first position in which seawater can enter the exit chamber from the reservoir 10, and a second position in which the seawater in the exit chamber has been expelled from the exit chamber.

The system preferably also includes one or more position

detectors, for example proximity detectors or switches 17, for detecting the position of the pressure multiplier 18.

The buoyancy control system further comprises a replacement fluid source 22 for providing fluid to the reservoir to replace seawater expelled therefrom. The replacement fluid source 22 comprises a gas tank which contains, for example, air or an inert gas (e.g. nitrogen or argon).

Figure 1 also shows how this embodiment of the buoyancy control system of the present invention also comprises an electronic control system 26, and is powered by a battery 28. The low power requirements of the buoyancy control system allow for the system to be powered by one or more 12 volt car batteries. The ingress and egress of water into and out of the buoyancy control system is indicated in Figure 1 by arrows A and B respectively.

Figure 2 shows additional features of this embodiment of the buoyancy control system of the present invention. Thus, Figure 2 shows that the buoyancy control system further comprises a gas valve 24, for example a gas spring valve, through which the replacement gas enters the reservoir. The gas valve 24 and the inlet valve 12 are each controlled by a 12 volt solenoid 32 and 30 respectively, which in turn are controlled by solenoid 38. The pressure multiplier 18 is controlled by a switching valve 34, which in turn is controlled by the proximity detectors or switches 17, through solenoid 38. The system further comprises non-return valves 19 associated with the chamber, for preventing seawater from reentering the reservoir 10. The hydraulic fluid is held within a tank 36. The buoyancy control system further comprises a pressure detector, for detecting the pressure in the reservoir in the

form of a transducer 40.

In operation, when a negative buoyancy is required, i.e. the volume of seawater in the reservoir 10 is to be increased, inlet valve 12 is opened to allow seawater into the reservoir. Replacement gas in the reservoir 10 is displaced to the tank 22 via the gas valve 24.

When a positive buoyancy is required, i.e. the volume of seawater in the reservoir 10 is to be decreased, outlet valve 14 is opened to allow seawater to leave the reservoir 10 and enter the exit chamber (not shown in the Figures). When the exit chamber has filled with seawater, the hydraulic pump 16 applies hydraulic pressure to the pressure multiplier 18, through hydraulic fluid from tank 36, which increases the pressure, and applies the increased pressure to the seawater in the exit chamber, thereby expelling all the seawater in the exit chamber through the outlet. When the seawater has been expelled from the exit chamber, the pressure multiplier is returned to its original position, and the cycle is repeated. The system preferably includes one or more position detectors, for example proximity detectors or switches 17, for detecting the position of the pressure multiplier 18. Thus, when a proximity detector or switch 17 detects that the pressure multiplier 18 is in a position at the end of the cycle described above, i.e. in the preferred embodiments described above, when the seawater has been expelled from the exit chamber, the electronic control system 26 can cause the pressure multiplier 18 to return to its original position, to expel more seawater from the reservoir. As referred to above, in the preferred embodiments of the buoyancy system, the pressure multiplier 18 is preferably a reciprocating pressure multiplier, in that it can reciprocate between a first

position in which seawater can enter the exit chamber from the reservoir 10, and a second position in which the seawater in the exit chamber has been expelled from the exit chamber. A proximity detector or switch 17 in these embodiments thus detects when the reciprocal pressure multiplier 18 in the second position, and on doing so sends a signal to the electronic control system 26, which returns the reciprocal pressure multiplier 18 to the first position.

The above described operations for achieving negative and positive buoyancy may be achieved either by pre-programming the electronic control system 26, by the electronic control system responding to signals sent by a controller at a home station, or automatically in response to external conditions (for example, depth data from a depth gauge).

The present invention can thus provide a buoyancy control system which is low-power, which can operate at depth, for example 3000m or greater, and can afford a higher buoyancy change than existing closed loop systems. The low-power requirement of the system of the present invention allows the system to be relatively lightweight and compact, which in turn allows it to be used as a "bolt-on" to existing underwater submersibles.

It will be understood that the embodiment illustrated shows one application of the invention only for the purposes of illustration. In practice the invention may be applied to many different configurations, the detailed embodiments being straightforward for those skilled in the art to implement.

CLAIMS

1. A buoyancy control system for controlling the buoyancy of an underwater submersible, which system comprises a reservoir for containing seawater, an inlet for the ingress of seawater into the reservoir, an outlet for the egress of seawater from the reservoir, and a hydraulic system for pumping seawater from the reservoir through the outlet, the hydraulic system comprising a hydraulic pump and a pressure multiplier, the hydraulic pump for applying pressure to the pressure multiplier, and the pressure multiplier for increasing the pressure applied thereto by the hydraulic pump, and for applying the increased pressure to seawater from the reservoir to thereby pump the seawater through the outlet.

2. A system according to claim 1 wherein the reservoir comprises a glass, steel or titanium sphere.

3. A system according to claim 1 or 2 wherein the reservoir can withstand pressures at undersea depths of 3000m or greater, and has a capacity to hold up to 35kg of seawater.

4. A system according to claim 1, 2 or 3 wherein the pressure multiplier comprises input and output surfaces in pressure transmitting relation, the output surface having a surface area less than the surface area of the input surface, the pressure increase generated by the pressure multiplier being determined by the ratio of surface areas of the input and output surfaces.

5. A system according to claim 4 wherein the input surface comprises a plate.

6. A system according to claim 4 or 5 wherein the output surface comprises a plunger or piston.

7. A system according to any preceding claim which further comprises an exit chamber into which seawater can enter from the reservoir, and from which the seawater is expelled through the outlet by the hydraulic system.

8. A system according to claim 7 which further comprises a non-return valve or valves associated with the chamber, for preventing seawater from reentering the reservoir.

9. A system according to claim 7 or 8 wherein the pressure multiplier is preferably a reciprocating pressure multiplier, in that it can reciprocate between a first position in which seawater can enter the exit chamber from the reservoir, and a second position in which the seawater in the exit chamber has been expelled from the exit chamber.

10. A system according to any preceding claim wherein the hydraulic system further comprises one or more position detectors, for detecting the position of the pressure multiplier.

11. A system according to claim 10 wherein the position detector comprises a proximity detector or switch.

12. A system according to any preceding claim which further comprises a replacement fluid source for providing fluid to the reservoir to replace seawater expelled therefrom.

13. A system according to claim 12 wherein the replacement fluid has a density less than that of seawater.

14. A system according to claim 13 wherein the replacement fluid comprises air or an inert gas.

15. A system according to any preceding claim which further comprises a pressure detector, for detecting the pressure in the reservoir.

16. A system according to claim 15 wherein the pressure detector comprises a transducer.

17. A system according to any preceding claim which further comprises an electronic control system for controlling the system components.

18. A system according to claim 17 wherein the electronic control system comprises means for transmitting data concerning the state of operation of the system to a home station.

19. A system according to any preceding claim which forms an integral part of a submersible.

20. A system according to any one of claims 1 to 19 for attachment to a submersible.

21. A hydraulic system for pumping seawater from a submersible reservoir, the hydraulic system comprising a hydraulic pump, and a pressure multiplier, the hydraulic pump for applying pressure to the pressure multiplier, and the pressure multiplier for increasing the pressure applied thereto by the hydraulic pump, and for applying the increased pressure to seawater from the reservoir to thereby pump the seawater from the submersible.

22. A hydraulic system according to claim 21 wherein the pressure multiplier preferably comprises input and output surfaces in pressure transmitting relation, the output surface having a surface area less than the surface area of the input surface, the pressure increase generated by the pressure multiplier being determined by the ratio of surface areas of the input and output surfaces.

23. A hydraulic system according to claim 22 wherein the input surface comprises a plate.

24. A hydraulic system according to claim 23 wherein the output surface comprises a plunger or piston.

25. A hydraulic system according to any one of claims 21 to 24 wherein the pressure multiplier is a reciprocating pressure multiplier, which can reciprocate between a first position in which, in use, seawater can leave the reservoir to be pumped from the submersible, and a second position in which the seawater from the reservoir has been pumped from the submersible.

26. A method for pumping seawater from a submersible reservoir, which method comprises applying hydraulic pressure to seawater from the reservoir by a hydraulic system comprising a hydraulic pump, and a pressure multiplier, wherein the hydraulic pump applies pressure to the pressure multiplier, and the pressure multiplier increases the pressure applied thereto by the hydraulic pump, and applies the increased pressure to the seawater to thereby pump the seawater from the submersible.

27. A method according to claim 26 used for controlling the buoyancy of the submersible.

28. A buoyancy control system substantially as hereinbefore described with reference to the accompanying drawings.

29. A hydraulic system substantially as hereinbefore described with reference to the accompanying drawings.

30. A method for pumping seawater from a submersible reservoir substantially as hereinbefore described with reference to the accompanying drawings.

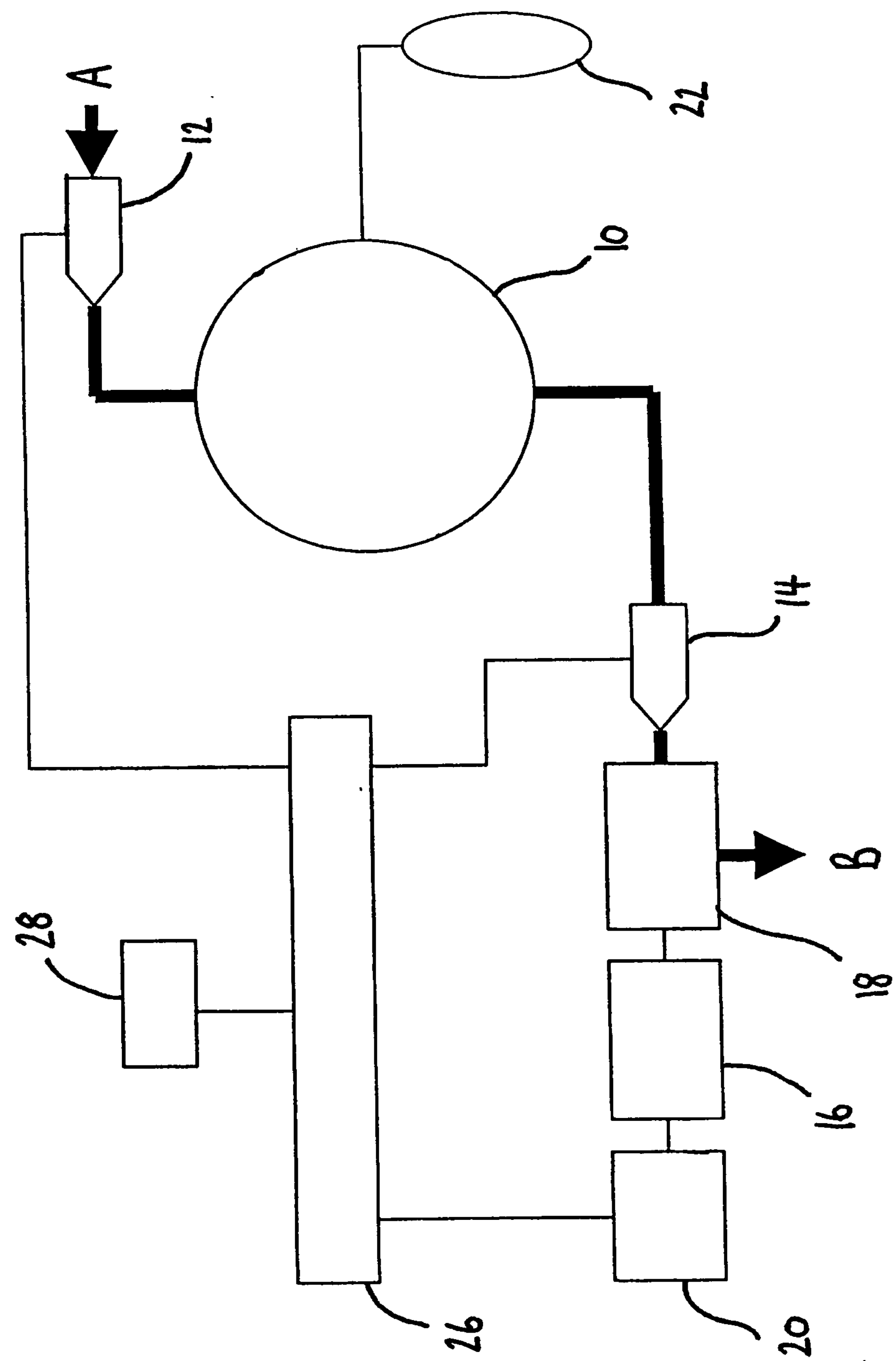

FIGURE 1

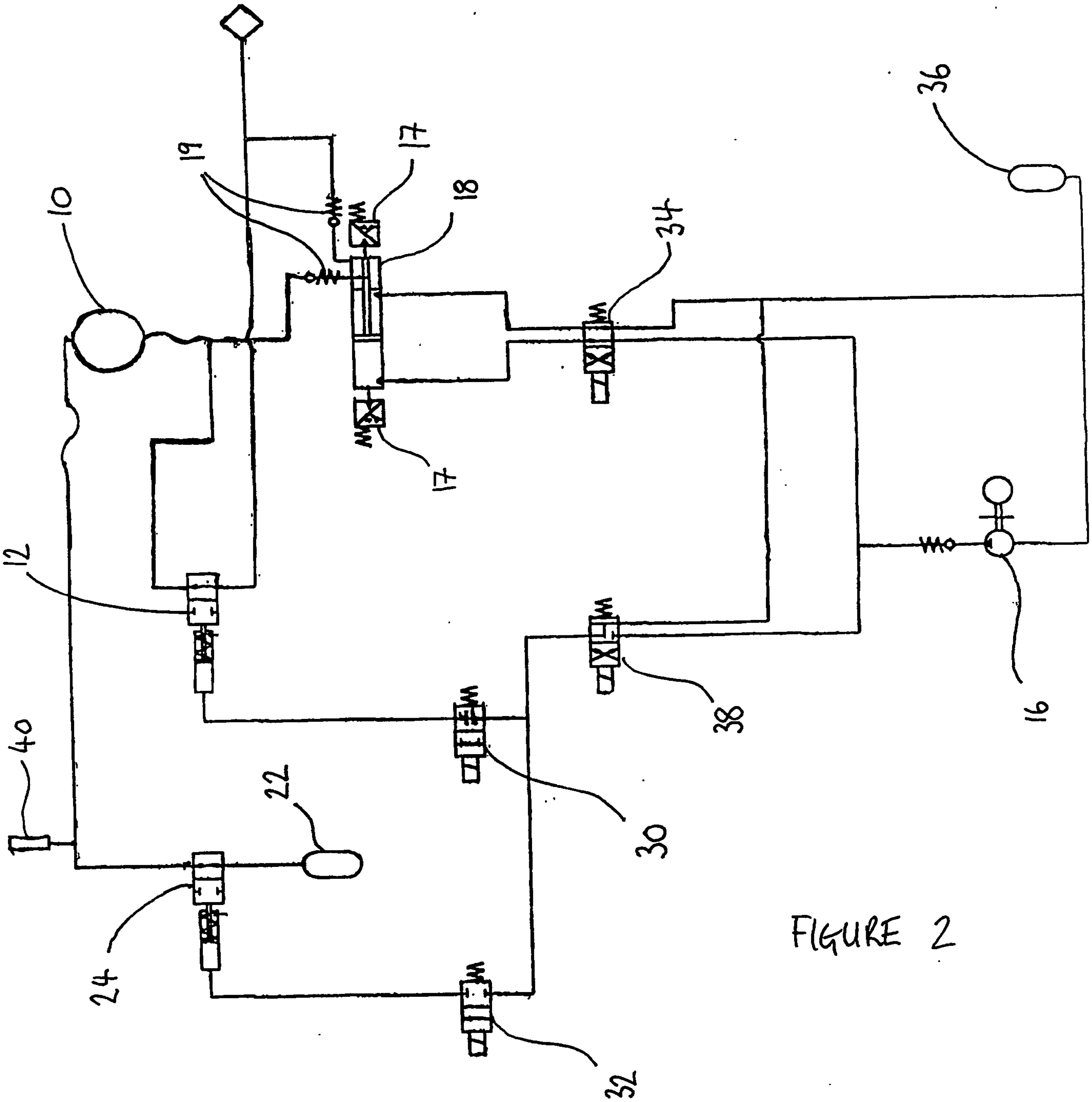

FIGURE 2

PCT/GB2004/003592